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DEFORMATION OF ELECTRON BEAM WELDED Ti-6Al-4V ALLOY SHEET UNDER SUPERPLASTIC CONDITIONS

by

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DEFORMATION OF ELECTRON BEAM WELDED Ti-6Al-4V ALLOY SHEET UNDER SUPERPLASTIC CONDITIONS

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SUMMARY

Electron beam welds in Ti-6Al-4V sheet deformed under superplastic conditions (at 800°C or 925°C at a strain rate of $2 \times 10^{-4}\ s^{-1}$) were less superplastic and deformed less than the adjacent sheet. This caused severe local thinning of the sheet when the weld direction deviated from the principal strain direction. However, deformation removed weld undercuts and caused acicular weld microstructures to become more like the equiaxed sheet microstructure. The implications for the superplastic forming of components from welded sheet, bar and extrusions are discussed.

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Introduction

In the manufacture of Ti-alloy sheet components by superplastic forming (SPF) various joining techniques may be used including diffusion bonding and fusion welding. Depending on the relative costs and component design, fusion welding may be carried out on preforms prior to forming superplastically. The effect of the fusion weld on sheet formability and on final mechanical properties must then be taken into account.

In TIG welded sheet the superplastic flow stress was found to be greater than in unwelded sheet by a factor 3 and the weld region deformed less than the parent sheet [1]. This effect has been exploited in creep tests in which welds near the end of the test piece gauge length were used to restrict deformation from the head of the test piece [2].

A more detailed investigation of the effect of fusion welds on superplastic deformation of Ti-6Al-4V has been carried out and some of the results are described in the present paper.

Experimental Details

Electron beam melt runs were made in conventionally rolled Ti-6Al-4V 3mm thick sheet with the fusion zone extending through the sheet thickness. The melt run directions were parallel (L), transverse (T), or 45° to the test piece axis (rolling direction) as shown in Fig 1. The test section was 25mm long and 16mm wide. The welds were tested either in the as welded (un-machined) *state* or after machining to equal depths on each surface to remove the weld undercuts. Uniaxial superplastic deformation tests were carried out in argon at 925°C and 850°C to about 300% extension at a true strain rate of $2 \times 10^{-4} s^{-1}$. Tensile tests were carried out at room temperature on welded sheet after superplastic deformation and machining.

A section through the as welded sheet is shown in Fig 2a. The fusion zone (FZ) plus heat affected zone (HAZ) was 3.5mm wide of which the HAZ was 0.5mm wide on each side of the weld. In the fusion zone coarse prior β-grains had transformed to acicular α' martensite. The microstructure changed progressively across the HAZ from the α' martensitic structure where the weld temperature had exceeded the β-transus to a more equiaxed α where the temperature remained in the α+β field, as described elsewhere [3]. The hardness of the fusion zone and of the parent sheet was 381 H_V and 361 H_V respectively. The difference between the minimum and maximum sheet thickness in the weld undercut region was equal to 30% of the sheet thickness.

Results

The appearance of the machined and unmachined welds in the L orientation test piece after superplastic deformation at 925°C is shown in Fig 3a-b. The weld in this

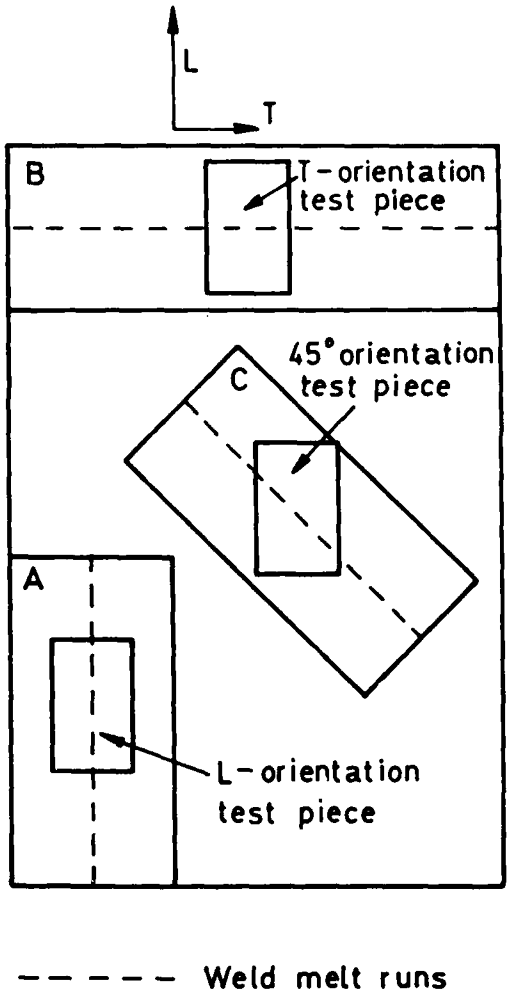

Fig 1 Orientation of test pieces relative to Electron beam melt run directions.

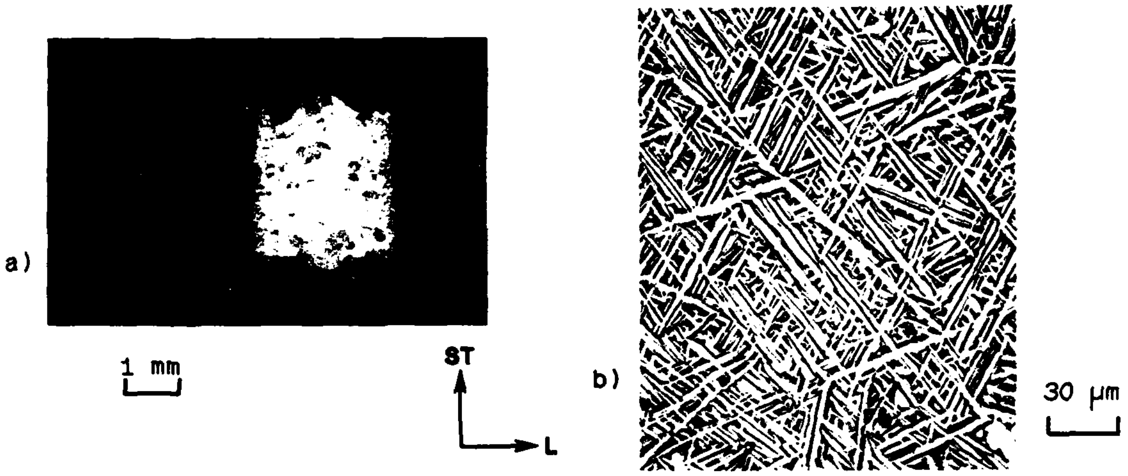

Fig 2 a) Section through as-welded sheet
b) Microstructure of fusion zone (FZ) after isothermal anneal, 2 hours 925°C, cooled 25°C/min

orientation extended with the sheet. In both the un-machined and machined weld the undercuts visible in Fig 2a were absent (Fig 3a-b) and the sheet thickness was uniform up to the peaks in the FZ. The machined test peice developed a ridge at the position of the FZ (Fig 3b). The differences in the sheet thickness at the FZ compared with the sheet after superplastic deformation was 31% and 15% for the un-machined and machined test pieces respectively, which is reflected in the thickness strains across the weld shown in Fig 4. Note that strains greater than 0.5 were obtained for the weld zone. This deformation in the weld produced a coarser and more equiaxed weld zone microstructure compared with isothermal annealing for the equivalent time at 925°C as shown by comparing Figs 2b and 3c. The HAZ was converted to an equiaxed grain microstructure of diameter $\sim$6μm which resembled the microstructure in the parent sheet.

The corresponding machined and un-machined welds in the T-orientation test pieces after superplastic deformation are shown in Fig 5a-b. Again the undercut grooves were absent after deformation although the FZ deformed much less than in the L-orientation test piece. For example after a

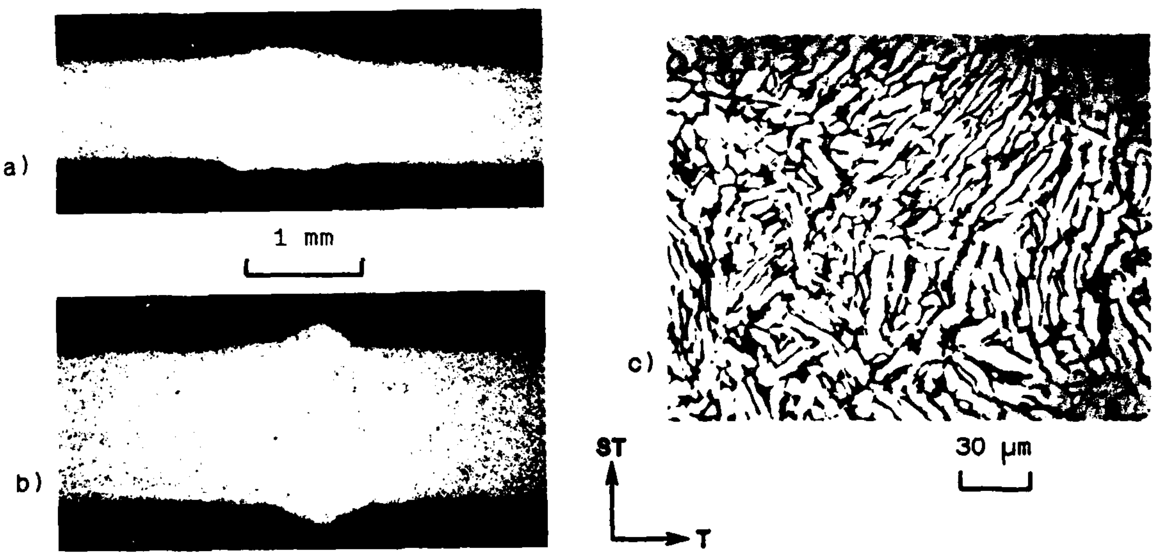

Fig 3 Section through (a) machined and (b) unmachined L-orientation test pieces after 300% extension at 925°C, (c) Fusion zone microstructure of machined test piece after deformation

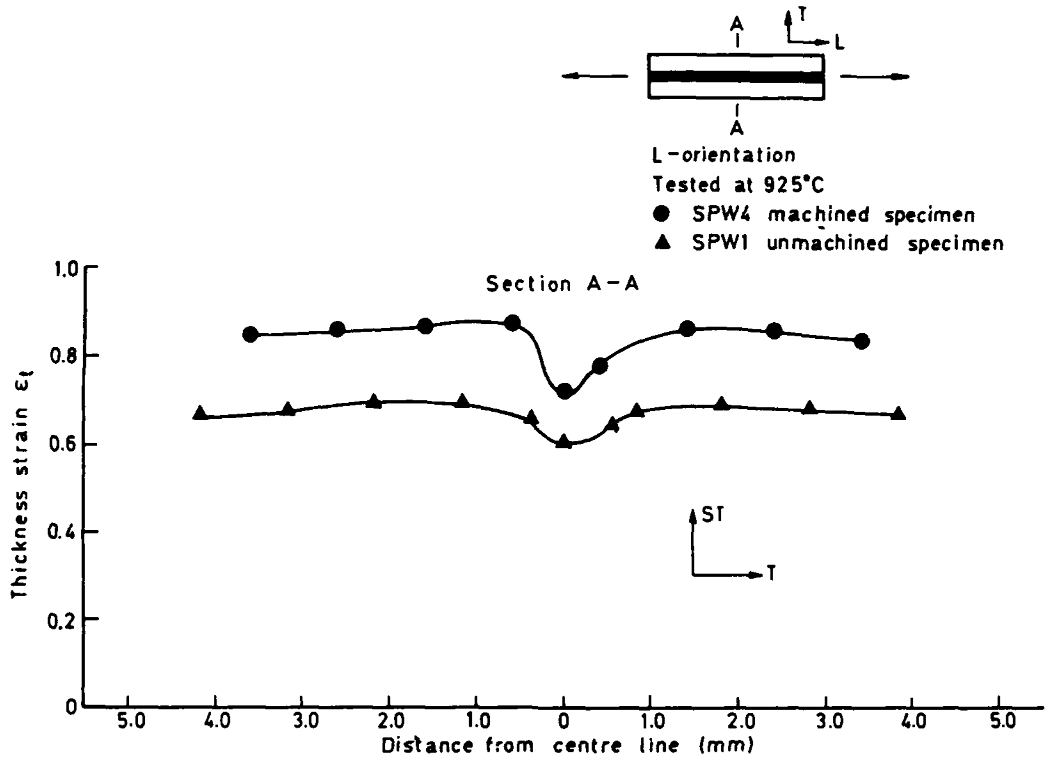

Fig 4 Thickness strain (ε_t) across L-orientation test pieces after 300% extension at 925°C

sheet thickness strain of 0.86 very little strain had occurred in the weld region (Fig 6). Nevertheless a significant change in the FZ microstructure occurred (Fig 5c) although it was less than in the L-orientation weld. This suggests the microstructural changes were primarily stress induced in this case.

The 45° oriented test piece deformed asymmetrically with a factor 2 difference in the thickness of the sheet on either side of the weld. This led to a reduction in the angle θ between the test piece axis and the weld direction from θ = 45° to θ = 13° after 300% strain.

Tests at 850°C produced similar results except that the sheet thickness varied more at this temperature than at 925°C. The initial superplastic flow stresses for the 3 weld orientations at both temperatures were in the order L>45°>T.

In the room temperature tensile tests fracture occurred in the parent metal for T and 45° oriented test pieces and there was no apparent effect of the weld on post formed tensile properties. The hardness of the weld zone after superplastic deformation was the same as that of the parent sheet.

Discussion

The important consequence of deforming fusion welds under superplastic conditions was the elimination of weld undercuts as shown in Figs 2a and 3a-b. The notch effect of undercut grooves has been reported to reduce the fatigue limit of Ti-6Al-4V alloy by 44% [4] whereas a thermal cycle alone reduced the fatigue limit by only 20% [5]. This suggests that the welded and superplastically formed sheet without weld undercuts may have a similar or greater fatigue limit than mill annealed Ti-6Al-4V with weld undercuts present.

Large differences (up to 150%) between the sheet and weld thicknesses were obtained depending upon the weld orientation. These differences were a minimum for L-orientation test pieces and a further reduction in the post formed thickness variation could be obtained by pre-machining the weld. However to remove undercuts a substantial reduction in the preform sheet thickness might be necessary.

The need to reduce the minimum weight of fuel tanks and pressure vessels has directed attention to the possibility of making such components by superplastic forming of Ti-alloy sheet, bar or extrusions. Because of the greater section size envisaged, fusion welding may be an attractive

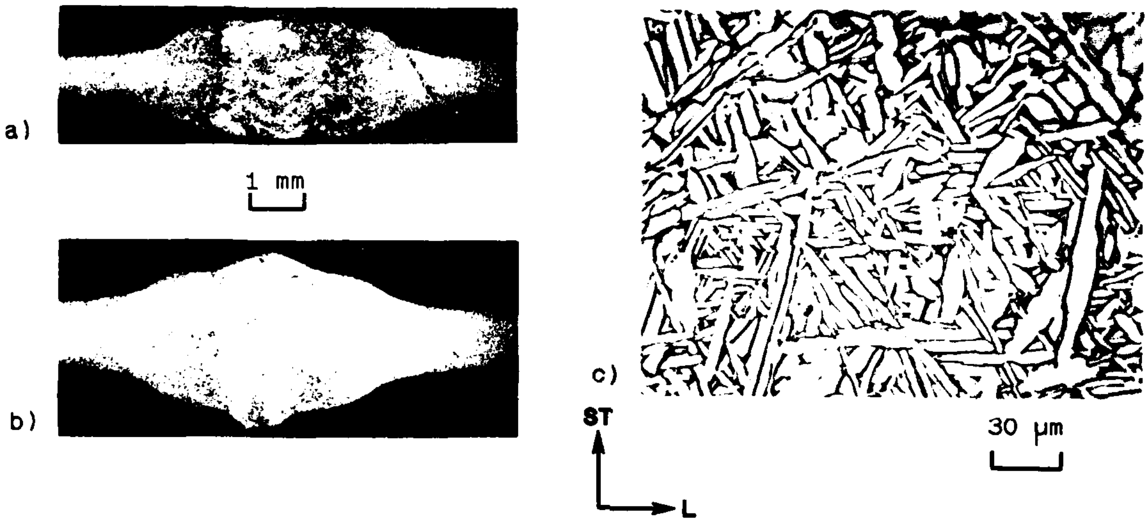

Fig 5 Section through (a) machined and (b) unmachined T-orientation test pieces after 300% extension at 925°C. (c) Fusion zone microstructure of unmachined test piece after deformation.

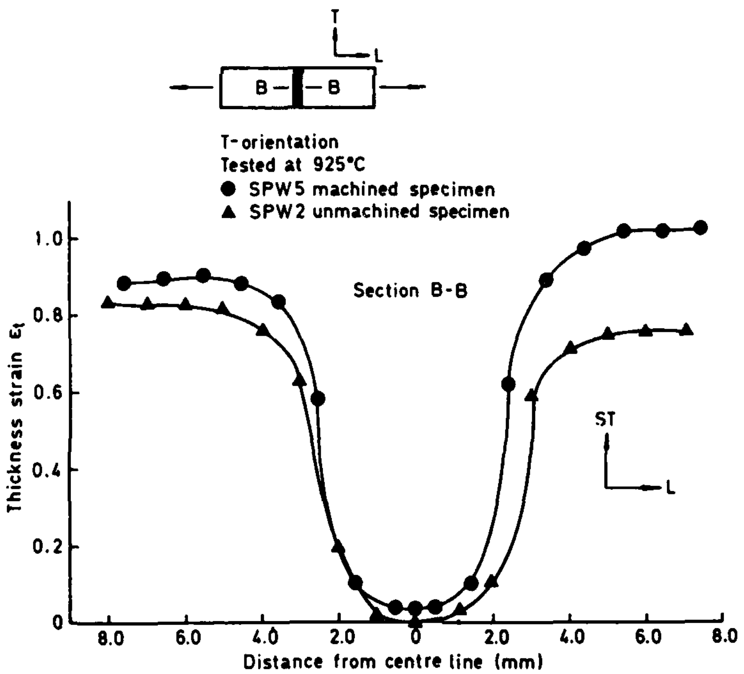

Fig 6 Thickness strain (ε_t) along the T-orientation test piece after 300% extension at 925°C.

preform manufacturing method. The welds may then influence the local sheet thickness and hence the design factors and structural efficiency. This effect on sheet thickness was accentuated in the 45° oriented test pieces, and when combined with a lower forming temperature or with very thin sheet, the thickness variation could lead to premature fracture during forming. Although the effects might differ in degree under biaxial conditions the results suggest that minimum sheet thickness variation is best achieved by aligning the weld along the principal strain direction as in the L-orientation test piece. In this orientation substantial deformation occurred in the weld which led to weld hardness and microstructures very similar to that of the surrounding sheet. Careful alignment of welds in preforms may then allow fusion welds to be combined with SPF/DB processing.

Conclusions

After deformation under superplastic conditions fusion welds in Ti-6Al-4V had microstructures and mechanical properties similar to those of the parent sheet provided sufficient deformation occurred in the weld zone. This was favoured by aligning the weld along the principal strain direction.

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17. Abstract

Electron beam welds in Ti-6Al-4V sheet deformed under superplastic conditions (at 800°C or 925°C at a strain rate of $2 \times 10^{-4}\ s^{-1}$) were less superplastic and deformed less than the adjacent sheet. This caused severe local thinning of the sheet when the weld direction deviated from the principal strain direction. However, deformation removed weld undercuts and caused acicular weld microstructures to become more like the equiaxed sheet microstructure. The implications for the superplastic forming of components from welded sheet, bar and extrusions are discussed.

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